BSM Searches at DØ

James Kraus
Michigan State University

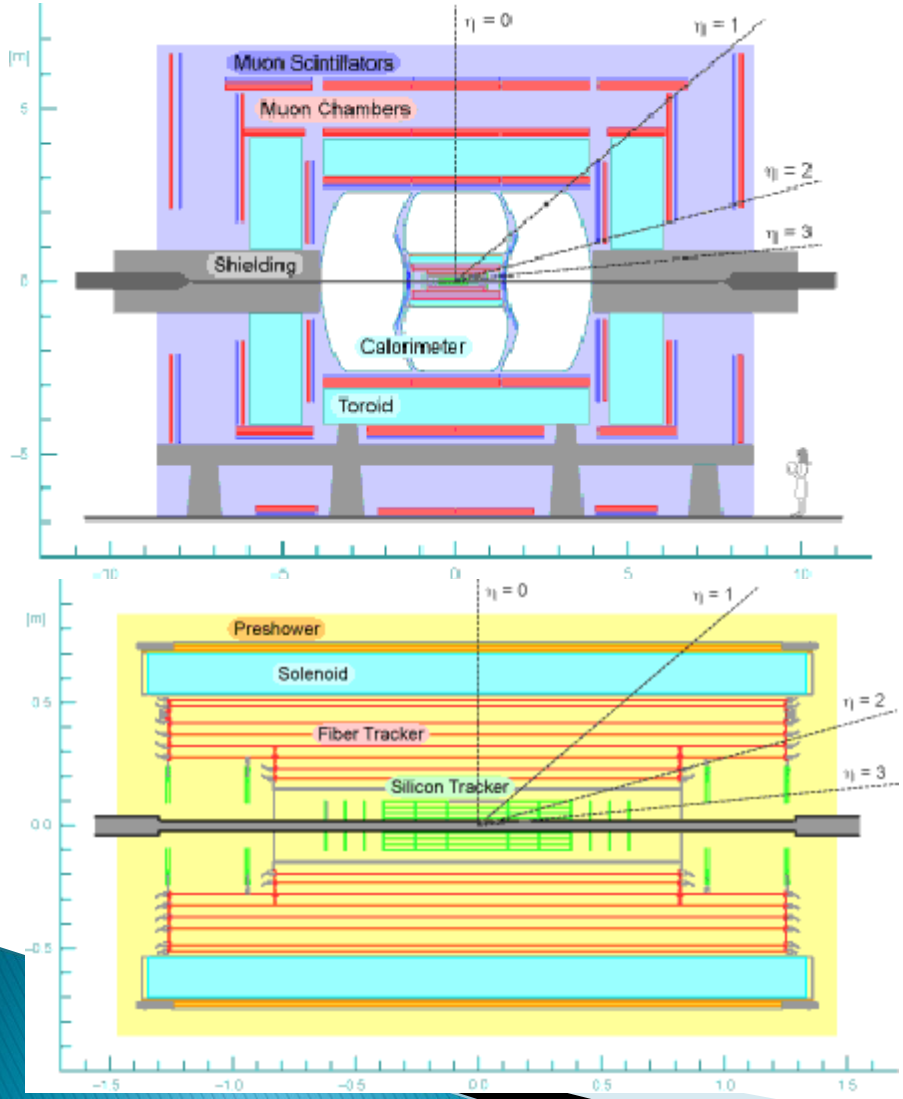
Beyond the Standard Model Searches at DØ

- The DØ Collaboration has produced many new limits on BSM Theories
  - Third generation Leptoquark (LQ) and SUSY limits in the $b\bar{b}$+Missing Transverse Energy (MET) final state
  - Randall-Sundrum (RS) Graviton search in the di-electron and di-photon final states
  - W' decays to WZ
  - Dark Photons from SUSY Hidden Valleys
  - Associated Chargino & Neutralino production decaying to 3 leptons and MET
  - And many more…

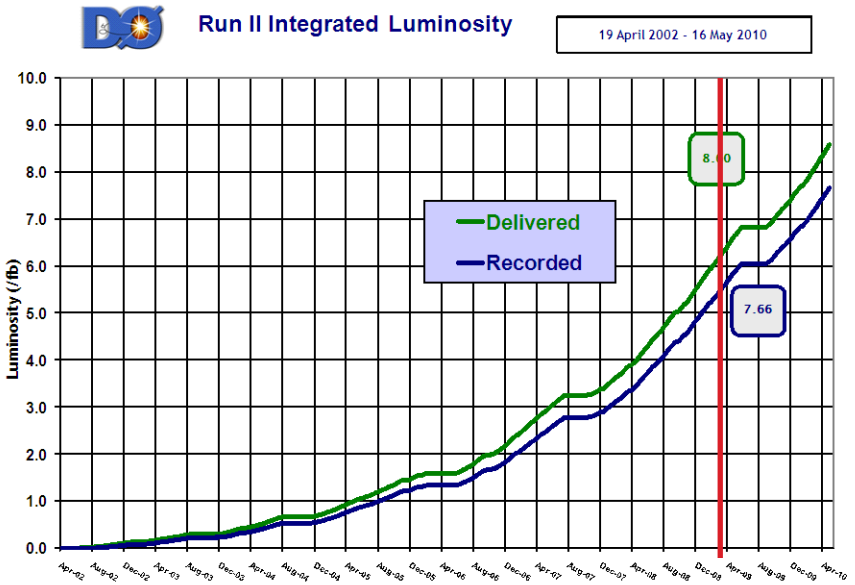
Beyond the Standard Model Searches at DØ

- The DØ Collaboration has produced many new limits on BSM Theories
  - **Third generation Leptoquark (LQ) and SUSY limits in the $b\bar{b}$+Missing Transverse Energy (MET) final state**
  - **Randall-Sundrum (RS) Graviton search in the di-electron and di-photon final states**
  - W' decays to WZ
  - Dark Photons from SUSY Hidden Valleys
  - Associated Chargino & Neutralino production decaying to 3 leptons and MET
  - And many more…

DØ Detector



- $p\bar{p}$ collisions
  - $\sqrt{s} = 1.96$ TeV
  - One bunch crossing per 396 ns

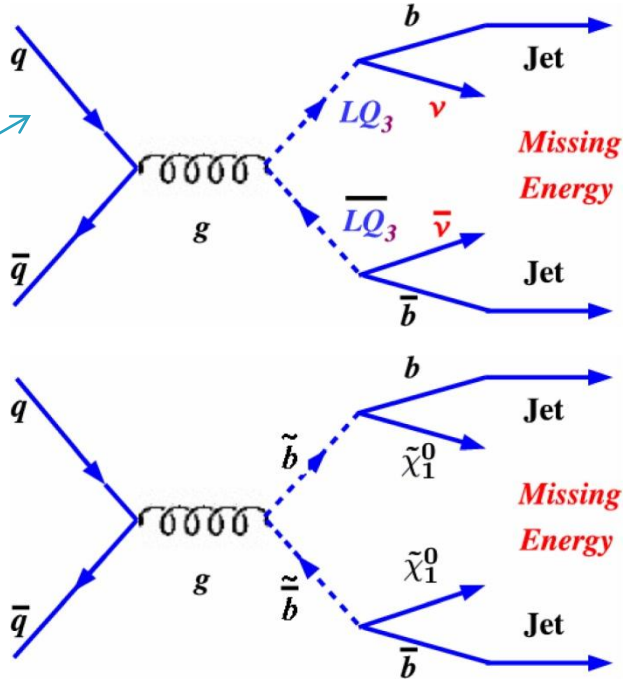


Leptoquarks and Supersymmetry

- LQ are exotic particles that would have color, charge, and both lepton and baryon number
  - A third generation LQ might decay to a $b + \nu_\tau$
- SUSY theories predict a SUSY partner for every Standard Model (SM) fermion
  - Consider part of parameter space where lightest sbottom squark $\tilde{b}_1$ has $m_{\tilde{b}_1} > m_b + m_{\chi_1^0}$ and $m_{\tilde{b}_1} < m_t + m_{\chi_1^\pm}$
    - $\tilde{b}_1 \to b\chi_1^0$
    - $\chi_1^{0/\pm}$ is the lightest neutralino/chargino
- **Both theories predict $b\bar{b}$+MET detector signature**

$b\bar{b}$ + MET Search

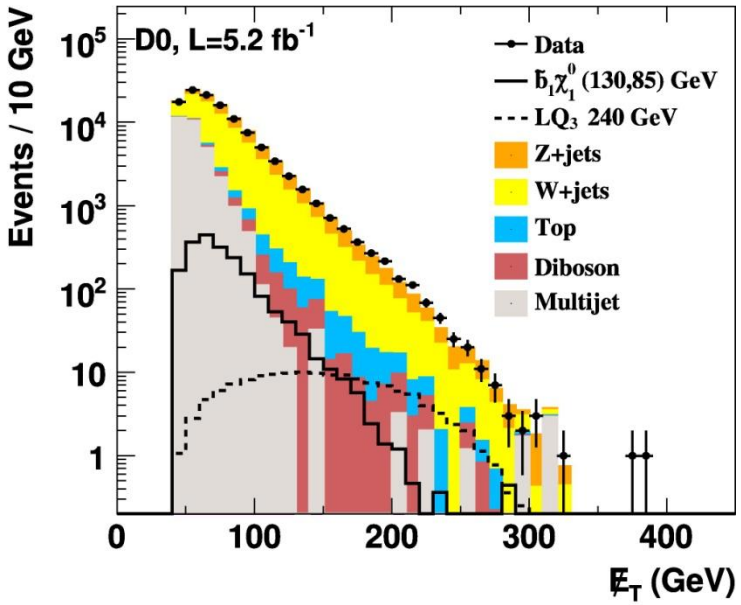
- $\int \mathcal{L} = 5.2\ \text{fb}^{-1}$
- Signal MC– PYTHIA 6.323
  - LQ masses varied between 200 and 280 GeV
  - $(\tilde{b}_1, \chi_1^0)$ masses varied by (80–260 GeV, 0–100 GeV)
- Backgrounds
  - With Real MET: $Z+jj \rightarrow \nu\nu+jj$, $W+jj \rightarrow \ell^+\nu+jj$, $t\bar{t}$
    - Modeled with ALPGEN and COMPHEP
  - With Fake MET: QCD multijet
    - Modeled with data



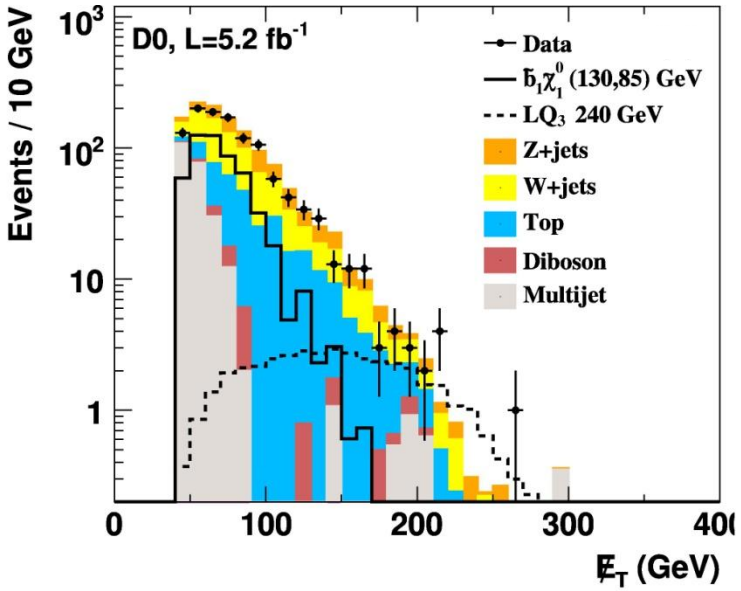
Initial Event Selection

- Require exactly 2 or 3 jets
  - $|\eta_{det}|<2.4$, $E_T > 20$ GeV,
  - Lead jets taggable, acoplanarity $< 165°$
- MET > 40 GeV
  - MET/GeV $< 80 - 40\times\Delta\phi_{min}$(MET, jets)
- Reject events with isolated leptons
- Calculate missing transverse momentum (MPT) from tracks, require $\Delta\phi$(MET,MPT)$<90°$
  - Events failing this cut are used to model QCD

b-tagging



before



after

- neural-net (NN) b-tagger rejects light quarks based on track information
  - 1st jet passing NN cut with 70% *b* efficiency
  - 2nd jet passing NN cut with 50% *b* efficiency
  - Light jet fake rates 6.5% & 0.5%, respectively
- Then apply additional cuts

Additional selection cuts

- Expect most energy in lead jets, so

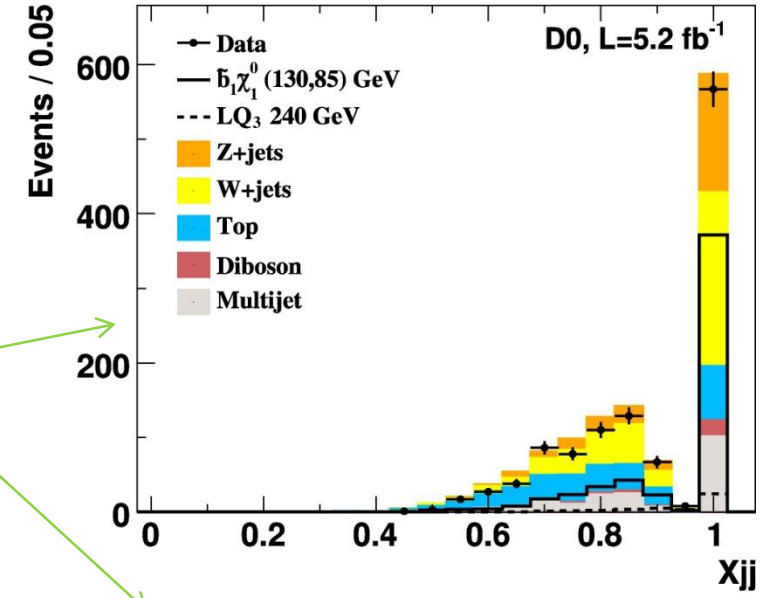
$$X_{jj} = \frac{E_T^{jet1} + E_T^{jet2}}{\sum E_T^{jets}} > 0.9$$

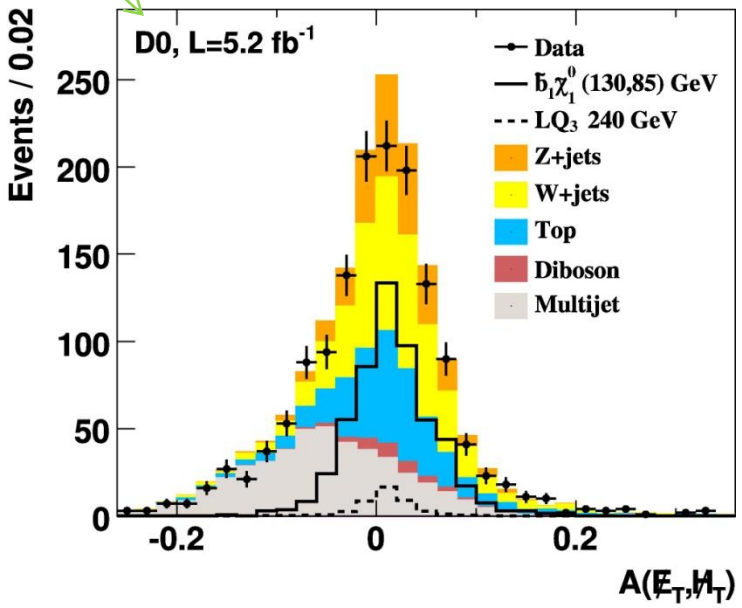
- To cut fake MET

$$-0.1 < A = \frac{MET - MHT}{MET + MHT} < 0.2$$

  - MHT =missing jet energy
  - $\Delta\phi_{min}$(MET,jets) > 0.6

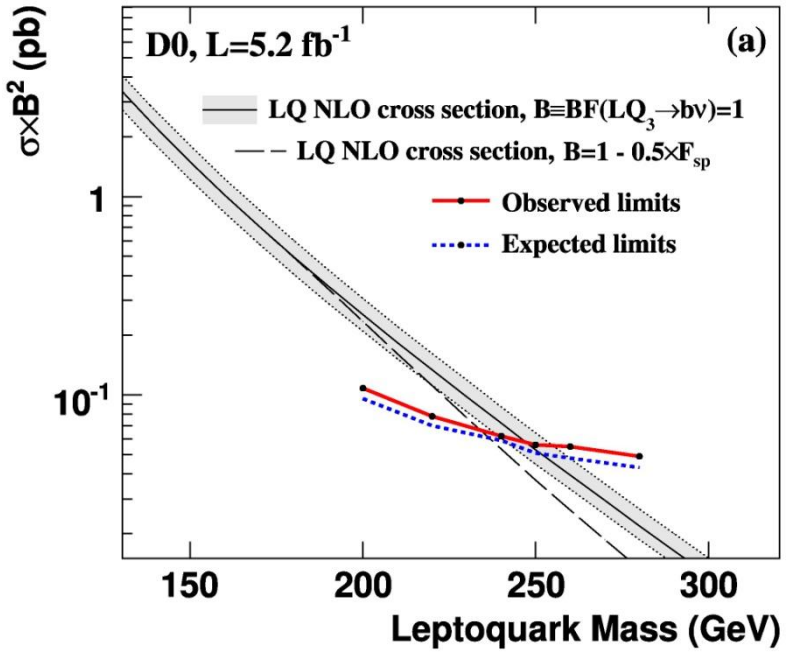
After *b*–tag

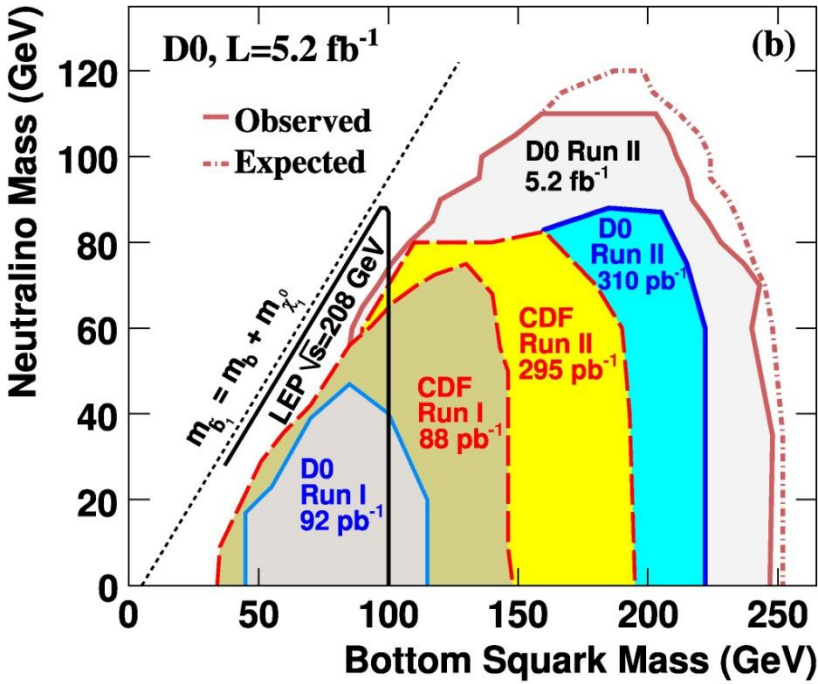




Limits on Sbottom, Neutralino, LQ Mass

- With a $LQ \rightarrow b\nu_\tau$ BR=1, $m_{LQ} > 247$ GeV @95%CL
  - With PDF error, $m_{LQ} > 238$ GeV @95%CL
  - Allowing $LQ \rightarrow t\tau$ $m_{LQ} > 234$ GeV @95%CL
- Green area indicates new exclusion region
  - With massless neutralino, $m_{\tilde{b}} > 247$ GeV @95% CL



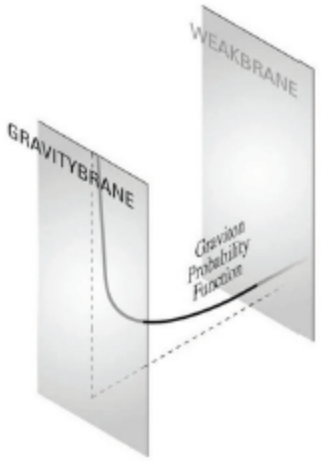


Randall-Sundrum (RS) Model

- Large difference between Planck scale (M_{Pl} $\approx 10^{16}$ TeV) and the electroweak scale (1 TeV)
  - Hierarchy problem
- In the RS Model, 5th dimension with a warped spacetime metric proposed
  - Bounded by two 3-dimensional branes
    - SM fields localized on one brane, gravity on other
  - Weakness of gravity from small overlap between graviton wavefunction and SM fields
  - SM TeV scales generated from geometrical exponential factor, $\Lambda_\pi = \overline{M}_{Pl} e^{-k\pi r_c}, \overline{M}_{Pl} = M_{Pl} / \sqrt{8\pi}$
    - k is curvature scale and r_c is compactification radius

$kr_c \approx 12$

RS Graviton



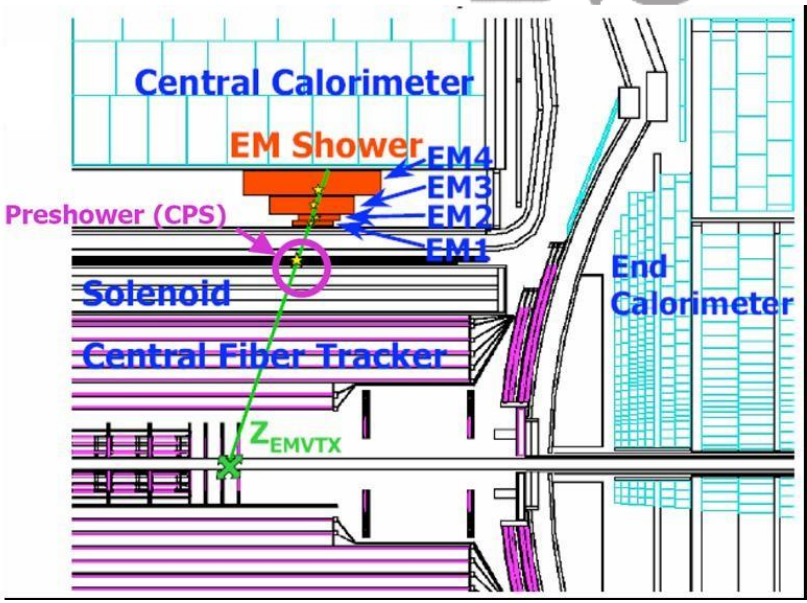
- Gravitons, G, are the only particles that propagate in the 5th dimension
  - Kaluza-Klein series of massive excitations
- Express k & r_c as 2 direct observables
  - Lightest graviton mass, M_1
  - Dimensionless coupling to SM fields, $k/\overline{M}_{Pl}$

- We expect M_1 in TeV range, $0.01 \leq k/\overline{M}_{Pl} \leq 0.1$
  - Otherwise fine tuning needed
  - Should decay to SM fermions and bosons

Search in decays to electrons & photons

- $\int \mathcal{L} = 5.4$ fb^{-1}
- Require two EM clusters
- Electrons & photons (e & γ), treated separately
  - Track info used to separate
- Signal and Backgrounds
  - PYTHIA G, 220 GeV$< M_1 <$1050 GeV, 0.01$< k/\bar{M}_{Pl} <$0.1
  - PYTHIA $Z/\gamma^* \rightarrow ee$ with mass-dependent NNLO k-factor
  - SM PYTHIA diphoton reweighed with DIPHOX
  - QCD jet$\rightarrow e/\gamma$ fake events estimated using data
  - Other backgrounds found to be small

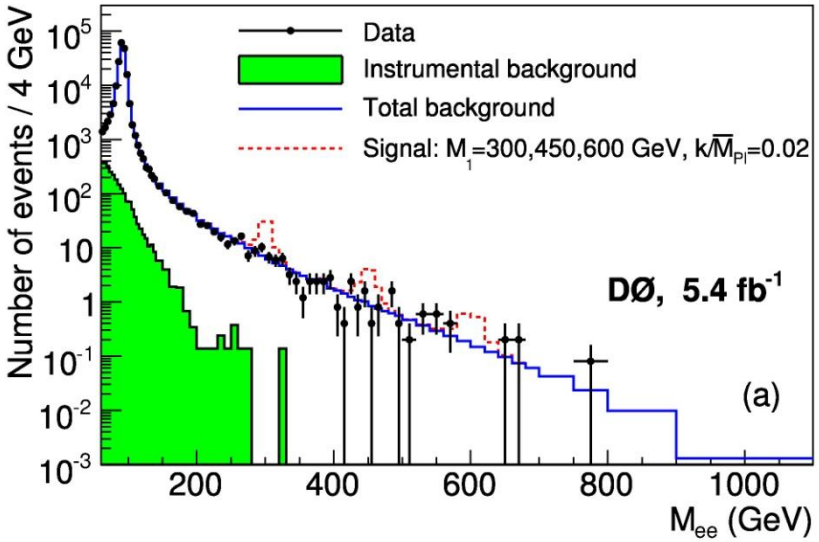
Electron and Photon ID

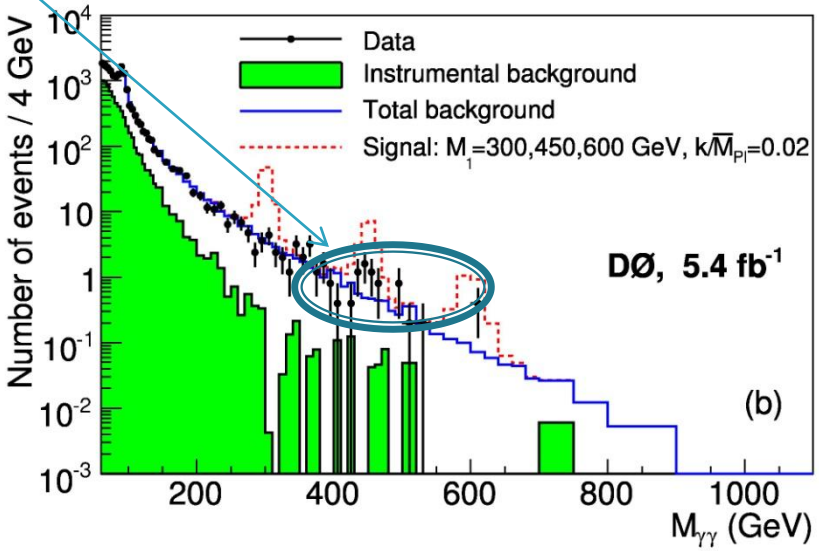


- Both e, γ require
  - $E_T > 25$ GeV, $|\eta_{det}| < 1.1$
  - 97% of energy in EM Calo
  - Isolated in calorimeter and tracker
  - NN discriminant on shape
- Electrons have an additional EM shower χ^2 cut
- Photons require additional r–ϕ width cut
- Both objects must point back to same primary vertex
  - CPS hits used to determine $\gamma\gamma$ vertex, if possible

Invariant Mass Distributions

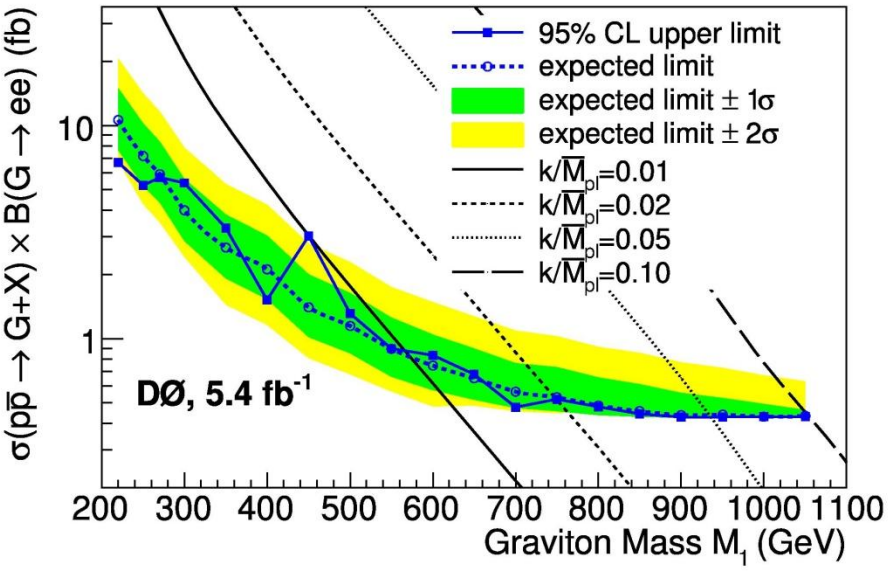
- Mass distributions generally in good agreement
- 2.30σ excess in $\gamma\gamma$ spectrum at 450 GeV
  - Reduced to 2.16σ when electron spectrum is included
- No significant excess

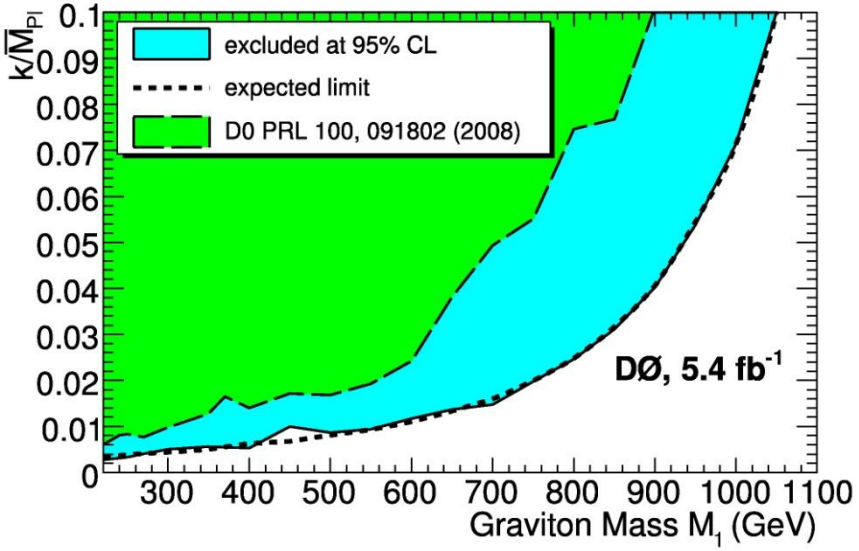


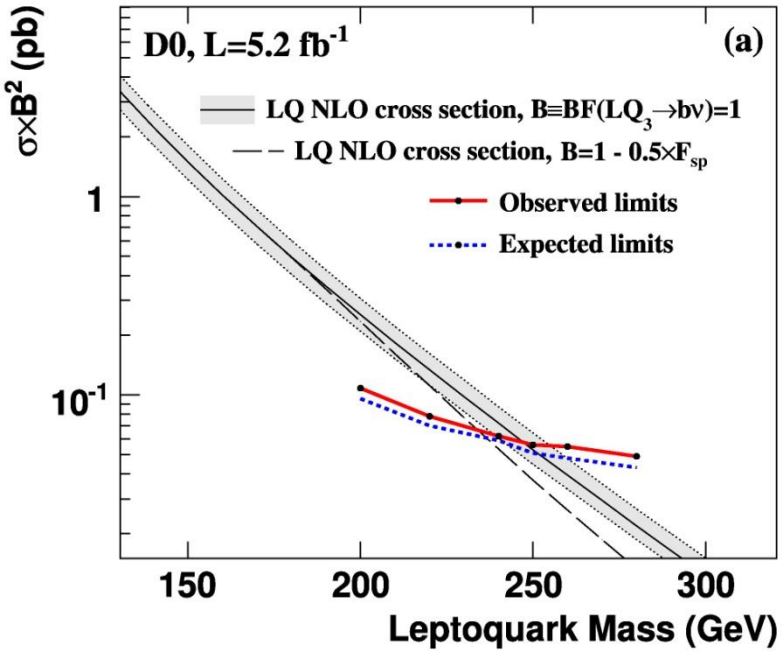


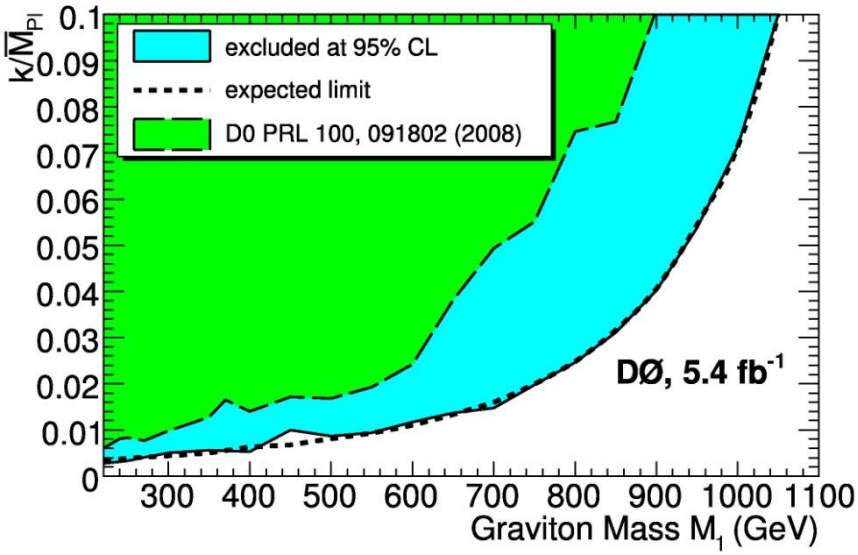
Limits on RS Model

- Limits on $\sigma \times B(G \rightarrow ee)$ between 6.7 fb and 0.43 fb for 220 GeV $< M_1 <$ 1050 GeV
  - $M_1 >$ 560 GeV @ 95% CL for $k/\bar{M}_{Pl} = 0.01$
  - $M_1 >$ 1050 GeV @95% CL for $k/\bar{M}_{Pl} = 0.1$









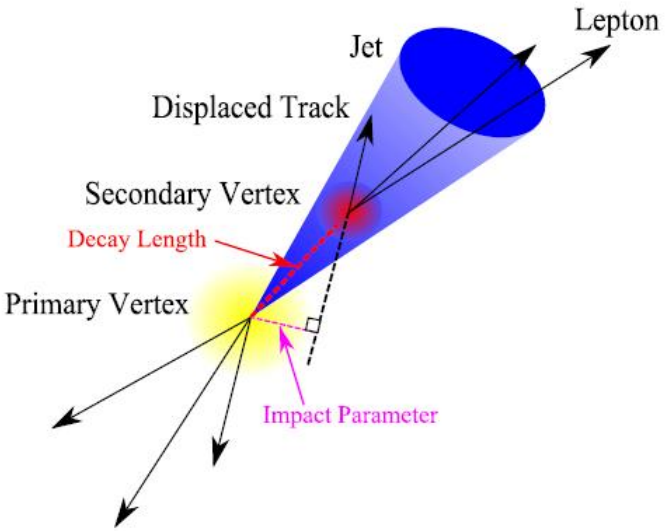
Conclusions

- Many new limits from DØ
  - LQ mass > 247 GeV @ 95% CL
    - Same limit on sbottom mass with neutralino mass = 0
    - Submitted to PLB, arXiv.org:1005.2222
  - Lower limits on M_1 of KK graviton between 560 and 1050 GeV for $0.01 \leq k/\bar{M}_{Pl} \leq 0.1$ @ 95% CL
    - Submitted to PRL, arXiv.org:1004.1826
- DØ now has collected over 7.66 fb^{-1}, so expect more new results!

Backup Slides

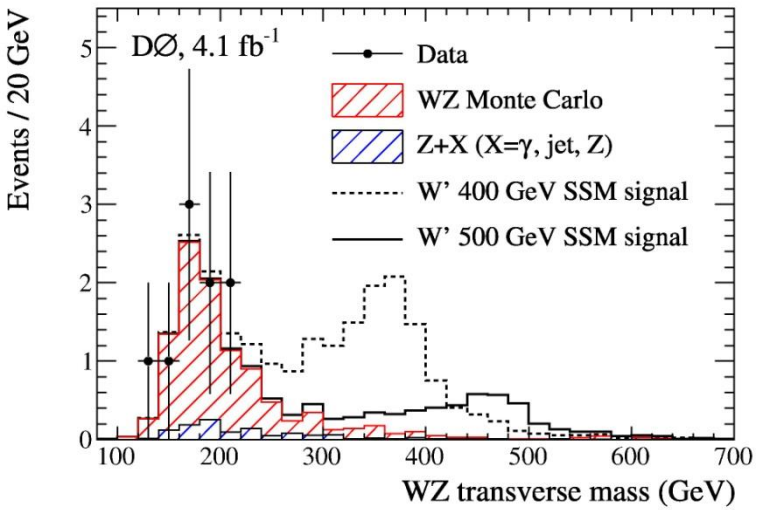
b-tagging NN

- The inputs to the *b*-tagging NN include
  - Probability jet originated from primary vertex
  - Number of tracks in jet
  - Decay length significance of secondary vertex
  - Mass of tracks from secondary vertex
    - Assumes all tracks pions
  - dR between secondary vertex and jet axis
  - Number of secondary vertices associated with jet



W' Search

- Search for $W' \rightarrow WZ \rightarrow 3\ell^{+}\nu$
  - ℓ=electron or muon
- Multiple theories predict W'
  - Sequential standard model (SSM), extra dimensions, little Higgs, techicolor
  - Limits Set on SSM and low-scale technicolor model (LSTC), for decays of ρ_T, a_T
- Backgrounds
  - SM WZ production, Z+jets, $Z\gamma$, ZZ



Limits on *W'* Production

- Limits better than expectation
  - within error on expected limit
  - SSM *W'* excluded for $188 < m_{W'} < 520$ GeV @95% CL
  - $208 < m_{\rho_T} < 408$ GeV excluded at @95% CL for $m_{\rho_T} < m_{\pi_T} + m_W$
- Published in PRL 104, 061801 (2010)

arXiv.org:0912.0715